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Path Averaged Boundary Layer Measurements Beneath Ice Using Acoustic Scintillation

Path averaged boundary layer measurements were carried out by the David Farmer group during the spring of 1989 at the Oceanography ice camp ("O" camp) North of Spitsbergen as part of the Coordinated Eastern Arctic Experiment (CEAREX). In this report, we describe the acoustic instrumentation used, summarize the field trip, and talk about the preliminary data analysis and scientific investigation which is underway at the Institute of Ocean Sciences.

ACOUSTIC INSTRUMENTATION

An acoustic instrument has been developed in order to study the turbulent boundary layer under the Arctic ice cover. The instrument comprises twelve transducers capable of both transmission and reception of a spread spectrum signal centered at 132.3 kHz. Pseudo-random phase-encoded binary sequences are transmitted. Real-time correlation is performed by vector signal processing hardware contained in pressure housings adjacent to each transducer. The accompanying electronics allow the measurement and storage on Video Cassette Recorder (VCR) tapes of time of arrival amplitude and phase of the received acoustic signals.

FIELD TRIP SUMMARY

We deployed the acoustic system at the CEAREX "O" camp during March and April 1989. The acoustic array was laid out beneath the floe so as to span both multiyear and young ice, thus providing contrasting turbulence regimes. The twelve transducers were deployed in pairs at two separate depths at the vertices of an equilateral triangle 200 m on a side, with one arm parallel to the runway, and the other two enclosing the McPhee the Stanton and the Farmer huts. Each pair was mounted on a heavy iron bar laid out horizontally beneath the surface of the ice with a nominal separation of 65 cm between the two transducers. Each of the twelve sonars was connected to surface instrumentation contained in our hut through multi-conductor cables.

The deployment of the first three pairs of transducers at a depth of 20 m beneath the surface of the water was completed on March 29. Data collected in this configuration was monitored and analyzed during the next three days in order to insure proper operation of the apparatus. The remaining three pairs were deployed 10 m beneath the surface on April 2, 3 and 4 respectively. On April 14 and 15, three pairs of transducers were raised to 8 m and the other three lowered to 85 m in order to study processes near the top and the bottom of the mixed layer. The sonars and the transducers were recovered on April 22 and 23. During the period from March 27 to April 23, nearly 350 gigabytes of data were recorded on 71 VCR tapes.

In addition to the scintillation array, we deployed a 12 kHz echo sounder on March 30 and took several depth readings until April 24. The echo sounder was not operated more than four times a day because it interfered with Stanton's and our instrumentation. Nevertheless, the frequency of the depth readings was sufficient because of the slowly varying bottom topography.

Although, the analysis and physical interpretation of the data could not be done in the field, a personal computer with a custom interface card was used to monitor and validate the data during operation of the acoustic instrumentation. Time series of the phase of the received signals were plotted for reciprocal paths. Smooth curves were observed with rms noise level not exceeding seven degrees of the carrier frequency. This corresponds to a time resolution of 150 nanoseconds which will allow an accuracy of better than 1 mm/s when determining path averaged current velocity using the reciprocal transmission technique.

PRELIMINARY DATA ANALYSIS

Analysis of the acoustic data is currently underway at the Institute of Ocean Sciences in British Columbia, Canada. The enormous volume of information, presents us with a formidable processing challenge. In the months following the experiment, software was developed to read data stored on VCR tapes, through a Pulse Code Modulation (PCM) unit and a custom built interface card, extract the useful information and store it on a hard drive. The software locates the correlation peaks of interest, identifies and validates them and then calculates travel time and phase of arrival. The data is thus reduced by a factor of 180, allowing the storage of the information contained on an entire VCR tape (5 GigaBytes) in one disk file. All this processing takes place in real time, i.e. 176 kiloBytes per second are read and processed.

Time series of travel time and phase of arrival were obtained. Travel time based on quadrature interpolation of the correlation peak is a coarse measurement. This is due to the relatively low sampling rate (once every third cycle of the carrier frequency), the bandwidth limitation of the acoustic instrument (21 kHz centred at 132 kHz) which rounds the shape of the correlation peak and the background acoustic noise. However, the phase of arrival of the acoustic signal can be used to fine tune the travel time measurements. This fine tuning is possible only if phase wrap around is resolved.

If the transmitting and receiving transducers were fixed relative to each other, the phase excursions between each ping would be small and easy to resolve. However, the moorings hanging from the pack ice allowed large motion between the transducers (20 cm to 50 cm for a carrier wavelength of 1.1 cm). Due to the low ping repetition rate (0.88 s), the phase excursion between two consecutive pings can be relatively large during periods of violent movement of the moorings. This problem is compounded when pings are lost due to various periodic equipment malfunctions. For the above reasons, resolving phase wrap-around is a difficult task.

Various strategies for resolving phase ambiguity were tried out. The most obvious method consists in adding or subtracting complete cycles from the phase in order to minimize excursions between consecutive pings. Another technique is to filter the travel time signal and use it as a guide for the phase. Finally, reciprocal transmission and other parallel acoustic paths can be used to help resolve this phase ambiguity. A combination of the above methods gave satisfactory results (see Figures 1, 2 and 3).

SCIENTIFIC INVESTIGATION

The acoustic data will be interpreted in terms of relevant boundary layer dynamics. The data set is uniqe in that it provides path-integrated measurements that complement the localized observations obtained by other investigators at the "O" camp. Precise time series of path-averaged current velocities and mean sound speed along each acoustic path will be used to investigate the mean flow field and the turbulent fluctuations. The low frequency variability will be used to look at the large scale modulations of the flow field. Shear can be determined since the measurements were made at two different depths. The triangular layout of the array is ideally suited to measure vorticity of the enclosed fluid using Stoke's theorem. The measurements at two depths make it possible to observe propagation of vorticity across the mixed layer, as it responds to changes of the forcing function. Acoustic signals reflected off the bottom of the ice can be used to monitor the growth rate of the ice.

CAPTIONS

Figure 1: Propagation travel time between transducers separated by two hundred meters along a North/South axis. The time series covers a period of one hour starting at 8:00 AM UT on April 8, 1989. The large excursions are caused by relative movements of the moorings of the order of 15 cm. The noise on the signal is ambiguity as discussed in the text.

Figure 2: Phase of arrival for the same transducers and period of time as in Figure 1. Phase ambiguity has been resolved with the methods discussed in the text. Note the smoothness of this curve compared to the one in Figure 1, thus affording a more precise measure of time of arrival.

Figure 3: Time of arrival difference between reciprocal travel for the same conditions as in Figure 1. This difference is proportional to path averaged current speed along the propagation path (2 microseconds corresponds to 1 cm/s). Note the reversal in current direction shown as a negative travel time difference.

Figure 1:

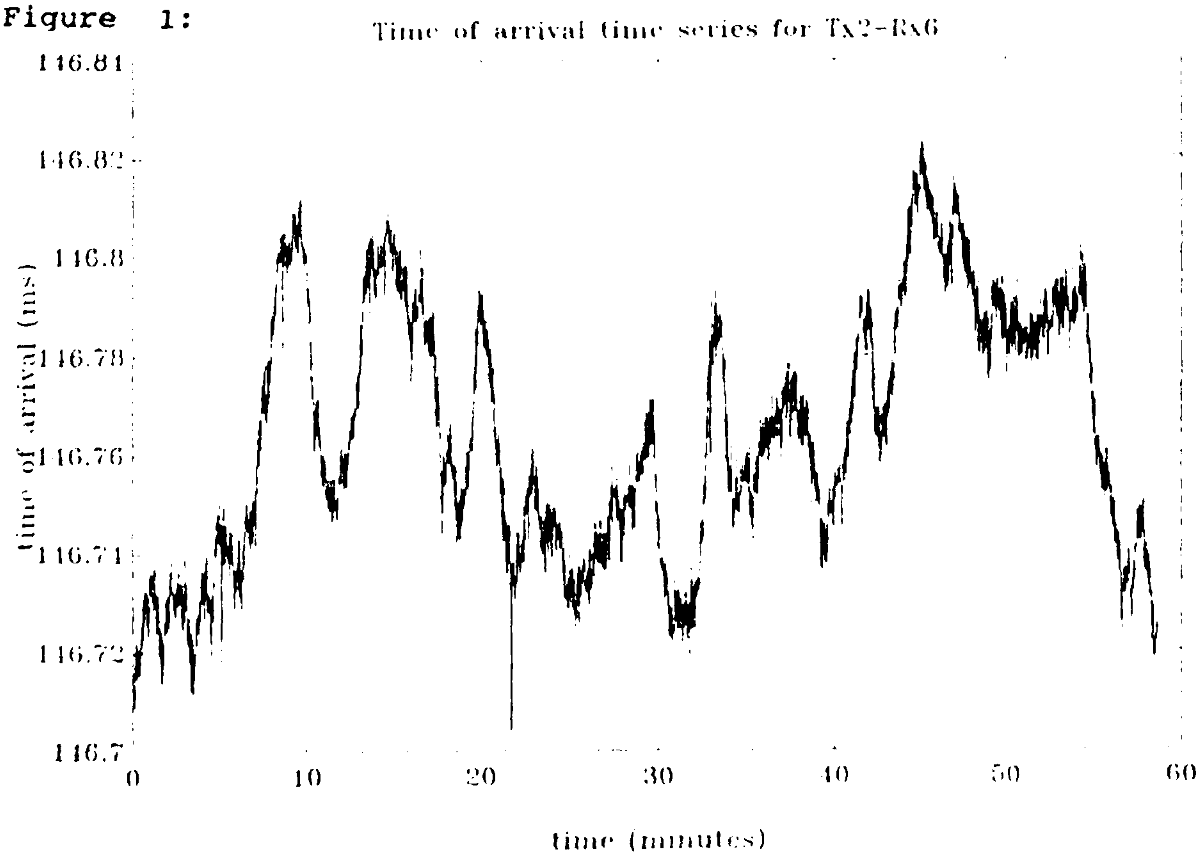


Figure 2:

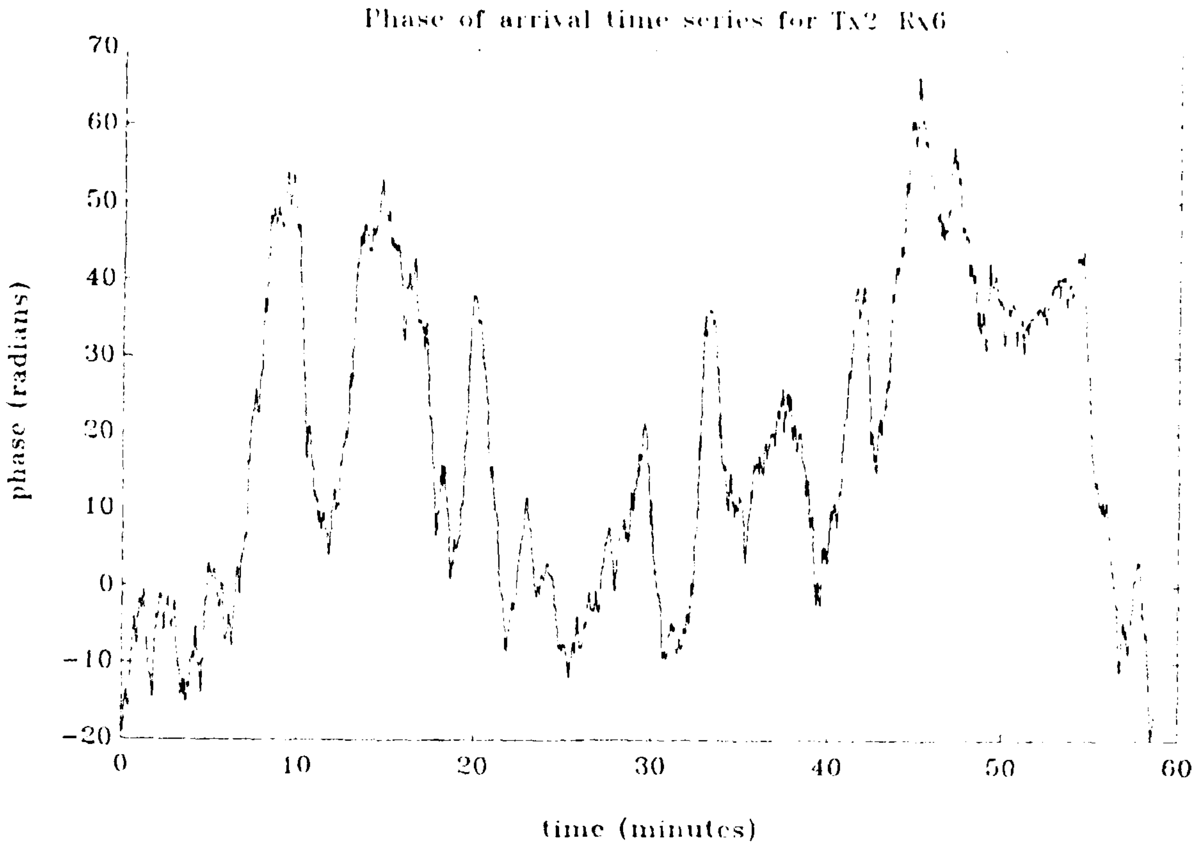
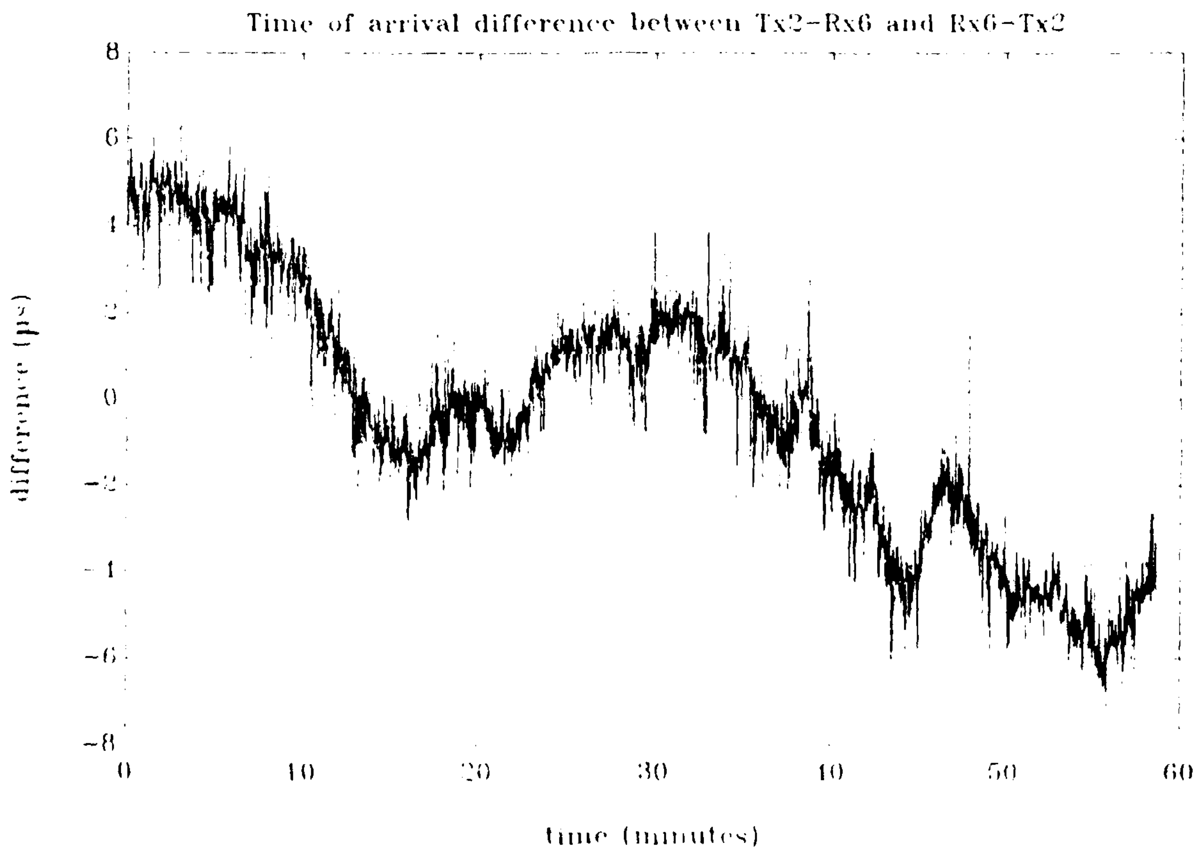


Figure 3:



10 October 89

Summary of Expenses for 1 October 88 to 30 September 89

ONR Grant No. : N00014-88-J-1102
DFO financial code: 2714-1430-1065

A.	Completion of instrument development	41125.30
B.	Mechanical work	6000.00
C.	Software development	5305.21
D.	Portable computer	10163.93
E.	Interface to PCM	1268.36
F.	Hand winch system	3475.85
G.	Supplies	6609.29
H.	CEAREX field trip:	
	Air freight	14502.75
	Travel and accomodation	7516.43
	CEAREX meetings	1032.88

Total for this funding period		$97,000.00
Previous expenditures (1 Oct 87 to 30 Sept 88)		$101,000.00

Total expenditures for this grant		$198,000.00

Note: Actual instrument development (part A) costs were $57,523.12 and mechanical work (part B) costs were $17,786.89. The additional funds were supplied by the Canadian government through the OERD program.